

## Specification

## Title of the Invention

Adaptive Antenna Control Method and Adaptive Antenna  
Transmission/Reception Characteristic Control Method

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Background of the Invention

The present invention relates to an adaptive antenna control method and adaptive antenna transmission/reception characteristic control method, 10 which can be used to, e.g., improve the frequency use efficiency in a radio communication system having a plurality of base stations by suppressing interference from a neighboring base station.

In a radio communication system that forms a 15 planar service area, such as a mobile communication system, radio zones formed by a number of base stations are combined to construct a wide service area. Radio zones formed at separate positions simultaneously use the same frequency as radio signals. With this method, 20 the frequency use efficiency can be improved.

Forming hexagonal zones is most effective to minimize, in each radio zone, interference from the remaining radio zones.

For example, as indicated by reference 25 (Okumura and Shinji, "Fundamentals of Mobile Communications", p. 195), when a service area is constructed by hexagonal zones, the number K of

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    frequencies required by this radio communication system  
    is given by

$$K = (1/3) \times (D/R)^2$$

    D: the distance between base stations of cells  
    5 (radio zones) which use the same frequency

    R: the radius of a cell

    When each cell has a regular hexagonal shape,  
    (D/R > 3) must hold. Hence, the number K of frequencies  
    is at least three.

10                  For the above reason, to provide a  
    communication service in a wide service area using a  
    conventional typical radio communication system, at  
    least three radio frequencies must be used.

15                  When an adaptive antenna is employed,  
    interference from another radio zone that uses the same  
    frequency can be suppressed.

20                  For example, a typical adaptive antenna as  
    shown in reference (R.A. Monzingo and T.W. Miller,  
    "Introduction to Adaptive Arrays", John Wiley & Sons,  
    Inc. 1980) has an arrangement shown in Fig. 9.

25                  Referring to Fig. 9, this adaptive antenna  
    comprises N antenna elements 901(1) to 901(N), weighting  
    circuits 902(1) to 902(N) and 912(1) to 912(N), weight  
    control unit 903, reference signal generation unit 904,  
    divider/combiner 905, and distributor 913.

    The weighting circuits 902(1) to 902(N) and  
    divider/combiner 905 are used for reception. The

weighting circuits 912(1) to 912(N) and distributor 913 are used for transmission. Each weighting circuit 902 weights the signal from a corresponding antenna element 901 with a complex number. The weight control unit 903 controls the value of the weight to be supplied to each weighting circuit 902 or 912. The divider/combiner 905 generates a signal by combining the signals of N systems, which are weighted by the respective weighting circuits 902. The distributor 913 distributes a signal to be transmitted to systems equal in number to the antenna elements 901.

When signals received by the antenna elements 901(1) to 901(N) are represented by  $x(1)$  to  $x(N)$ , the values of weights in the weighting circuits 902(1) to 902(N) are represented by  $w(1)$  to  $w(N)$ , and a desired signal component is represented by  $d$ , a weight  $W_{OPT}$  for minimizing the error between the desired signal component  $d$  and the reception signal obtained at the output of the divider/combiner 905 is given by

$$20 \quad W_{opt} = R_{xx}^{-1} r_{xd} \quad \dots (13)$$

$$R_{xx} = E[X^* X^T] \quad \dots (14)$$

$$25 \quad r_{xd} = \begin{pmatrix} \overline{x(1) \cdot d^*} \\ \overline{x(2) \cdot d^*} \\ \vdots \\ \overline{x(N) \cdot d^*} \end{pmatrix} \quad \dots (15)$$

$$X = \begin{pmatrix} x(1) \\ x(2) \\ \vdots \\ x(N) \end{pmatrix} \quad W_{opt} = \begin{pmatrix} w_{opt}(1) \\ w_{opt}(2) \\ \vdots \\ w_{opt}(N) \end{pmatrix} \quad \dots (16)$$

where

5 suffix \*: conjugate transposition

suffix T: transposition

E[·]: expected value

X: input signal vector

x(i): reception signal of ith antenna element

10 d: desired signal

w<sub>opt</sub>(i): weight for ith antenna element

When the directional pattern of the antenna is controlled by generating such a weight, a null is formed in the directional pattern with respect to the direction 15 of an interference station. Hence, the influence of the interference wave from the interference station can be suppressed. A "null" means that the radiation field or reception field strength becomes 0.

By installing an adaptive antenna in a base 20 station, even when, e.g., communication is executed using the same radio frequency in adjacent radio zones, the influence of an interference wave from a neighboring radio zone can be suppressed.

However, assume that a base station uses an 25 adaptive antenna, and another base station (interference station) that uses the same frequency as that of the n station (base station) is present in the direction of a

target terminal station viewed from the base station.

In this case, if the directional pattern of the antenna is controlled to suppress the influence of the interference wave from the interference station, the

5 signal from the target terminal station is also suppressed, and the transmission quality inevitably degrades.

In a radio communication system, limited frequency resources must be effectively used. However,

10 in a radio communication system which provides a radio communication service in a wide range using a plurality of base stations, as described above, since interference from a neighboring zone to a given base station and interference from the given base station to the

15 neighboring zone are present, zones adjacent to each other cannot use the same frequency.

When an adaptive antenna is used, the interference wave from a neighboring zone can be suppressed, and therefore, the same radio frequency can

20 be used in adjacent radio zones. However, no sufficient interference reduction capability can be obtained only with the control of a conventional adaptive antenna.

Especially, when a target terminal station is present in the direction of the zone of the neighboring base

25 station, the interference unavoidably increases.

#### Summary of the Invention

It is an object of the present invention to

provide an adaptive antenna control method and adaptive antenna transmission/reception characteristic control method capable of improving the frequency use efficiency in a radio communication system.

5           In order to achieve the above object, according to the present invention, there is provided an adaptive antenna control method used for a radio communication system built by a plurality of radio base stations and a plurality of terminal stations capable of  
10 communicating with the radio base stations, each radio base station including an adaptive antenna having a plurality of antenna elements, a distributor for generating signals to be input to the plurality of antenna elements by branching a signal of one system to  
15 be transmitted, and weighting circuits for respectively weighting transmission signals to the plurality of antenna elements, wherein for reception by each terminal station, an interference wave power given by the transmission signal from each of the plurality of radio  
20 base stations is estimated, and a weight in the adaptive antenna of each radio base station is determined to minimize a sum of square errors between reception signals and desired signals for all the radio base stations which simultaneously use the same communication  
25 channel.

Brief Description of the Drawings

Fig. 1 is a sequence chart showing the control

sequence of an adaptive antenna control method related to a downlink according to the first embodiment;

Fig. 2 is a sequence chart showing the control sequence of the adaptive antenna control method related to an uplink according to the first embodiment;

Fig. 3 is a block diagram showing the arrangement of a communication system;

Fig. 4 is a flow chart showing control of an intensive control station related to a downlink according to the second embodiment;

Fig. 5 is a flow chart showing control of the intensive control station related to an uplink according to the second embodiment;

Fig. 6 is a graph showing the characteristic of the downlink of the first embodiment;

Fig. 7 is a graph showing the characteristic of the uplink of the first embodiment;

Fig. 8 is a graph showing the characteristic of the second embodiment;

Fig. 9 is a block diagram showing the arrangement of an adaptive antenna; and

Fig. 10 is a view for explaining the third embodiment.

#### Description of the Preferred Embodiments

The present invention will be described below with reference to the accompanying drawings.

(First Embodiment)

An adaptive antenna control method according to an embodiment of the present invention will be described with reference to Figs. 1 to 3, 6, and 7. This first embodiment corresponds to claims 1 to 4 and 6  
5 to 9.

Fig. 1 shows the control sequence of the adaptive antenna control method related to a downlink according to the first embodiment. Fig. 2 shows the control sequence of the adaptive antenna control method  
10 related to an uplink according to the first embodiment. Fig. 3 shows the arrangement of a communication system. Fig. 6 shows the characteristic of the downlink of the first embodiment. Fig. 7 shows the characteristic of the uplink of the first embodiment.

15 In the first embodiment, assume that the present invention is applied to control a communication system as shown in Fig. 3. That is, a plurality of terminal stations 101 are present in a relatively narrow area. Each terminal station 101 can execute radio  
20 communication with a plurality of base stations 102. That is, each terminal station 101 can communicate with another terminal through any one of the base stations 102.

In this example, assume that the plurality of  
25 terminal stations 101 and the plurality of base stations 102 simultaneously use the same communication channel, and space division multiple transmission is implemented

using, e.g., the directivity of an antenna. For these purposes, each base station 102 has an adaptive antenna which basically has the same arrangement as that shown in Fig. 9. Additionally, in this example, assume that  
5 each terminal station 101 has a transmission power adjustment function.

The plurality of base stations 102 are connected to an intensive control station 103 through a wired network. The base stations 102 and intensive  
10 control station 103 may be connected through a wireless network. The intensive control station 103 concentrically controls the plurality of base stations 102 and the plurality of terminal stations 101 and controls the directional pattern of the antenna in each  
15 base station 102 and the transmission power of each terminal station 101.

In the example shown in Fig. 3, three terminal stations 101 and three base stations 102 are controlled. However, the number of terminal stations 101 and the  
20 number of base stations 102 are changed as needed. For the adaptive antennae, the plurality of base stations 102 need not always have antenna elements in equal number. Control of a downlink related to communication from the base station 102 to the terminal station 101  
25 and control of an uplink related to communication from the terminal station 101 to the base station 102 are independently executed.

Downlink control will be described first with reference to Fig. 1. For the descriptive convenience, this example assumes that the base station 102(2) and terminal station 101(1) communicate, and control is 5 executed to suppress the interference for reception at the terminal station 101(1) by signals transmitted from the remaining two base stations 102(1) and 102(3) which use the same communication channel.

Referring to Fig. 1, first, each of the base 10 stations 102(1), 102(2), and 102(3) transmits a predetermined known signal  $S_t$  to the terminal station 101(1). In this case, the signals  $S_t$  are transmitted using different communication channels. That is, communication channels for which at least one of the 15 frequency, timing, and spreading code is different are used.

In step S11, the terminal station 101(1) checks the correlation between the signal ( $S_t$ ) held by itself and each of the reception signals received from 20 the base stations 102 via the different communication channels, thereby estimating a transfer function. A transfer function is obtained for each antenna element of each base station 102.

To estimate a transfer function, a method 25 indicated by, e.g., reference (D. Gerlach and A. Paulraj, Acoustics, Speech and Signal Processing, ICASSP, vol. 4, pp. IV/97 - IV100, 1994) is used.

All transfer functions estimated by the terminal station 101(1) are transferred to the intensive control station 103 through the base station 102(2) in this case. On the basis of the transfer function received for each base station, the intensive control station 103 determines a weight vector for the adaptive antenna in each of the base stations 102(1), 102(2), and 102(3) such that the interference power at the terminal station 101(1) is minimized.

Assume that the nth base station 102 communicates with the mth terminal station 101. An interference power  $U(m)$  received by the mth terminal station 101 is given by

$$15 \quad U(m) = \sum_{\substack{k=1 \\ (k \neq n)}}^N \left| \sum_{j=1}^P w_d(k,j) V_d(m,k,j) \right|^2 \quad \dots (21)$$

$w_d(k,j)$ : weight for antenna element in downlink

$V_d(m,k,j)$ : transfer function of antenna element in downlink

20 P: number of antenna elements

N: number of base stations

When the plurality of terminal stations 101 are simultaneously communicating, the interference is preferably reduced for the entire system. For example, 25 in a communication channel with a lowest transmission quality, the transmission power of the base station 102 is preferably increased. In a communication channel

with a high transmission quality, no problem is posed even when the transmission power of the base station 102 is suppressed.

To control the interference on the plurality  
5 of terminal stations 101 altogether, the intensive control station 103 executes control by obtaining an evaluation index  $E_{down}$  of the entire downlink from

$$E_{down} = \sum_{k=1}^K U(k) \quad \dots (22)$$

K: number of terminal stations

10 That is, the intensive control station 103 selects a combination of weight vectors for the base stations 102, with which the evaluation index  $E_{down}$  is minimized, thereby suppressing degradation in transmission quality due to the interference to the minimum.  
15

As shown in Fig. 1, the weight vectors determined by the intensive control station 103 are transferred to the base stations 102(1), 102(2), and 102(3). Each of the base stations 102(1), 102(2), and 20 102(3) supplies to a weighting circuit 912 of the adaptive antenna the weight vector assigned to itself by the intensive control station 103. With this processing, the directional patterns of the antennas of the base stations 102(1), 102(2), and 102(3) are determined.

25 The characteristic of the downlink in executing the control shown in Fig. 1 was simulated

using a computer. Fig. 6 shows the result compared with a conventional method. This simulation was done assuming the following conditions. All base stations and terminal stations were completely synchronized, and  
5 the base stations and terminal stations transmitted signals with the same frequency, timing, and spreading code.

- Radius of cell formed by base station: 250 m  
10 Number of antenna elements of adaptive antenna of each base station: 4 elements  
Layout of antenna elements: circular array  
Directivity of antenna element:  
omni-directional in horizontal plane  
Antenna element spacing:  $0.5\lambda$   
15 Delay profile: exponential model  
Delay spread: 0.1 symbol length  
Number of base stations: 36  
Number of terminal stations: 36  
Angular spread of incoming wave:  $120^\circ$   
20 For the conventional method, assume that the adaptive antennae were individually controlled for the respective base stations, as shown in, e.g., reference (R.A. Monzingo and T.W. Miller, "Introduction to Adaptive Arrays", John Wiley & Sons, Inc. 1980).  
25 The layout of the terminal stations was changed 100 times at random, and the 50% value of the cumulative probability of the transmission quality of a

terminal station with a lowest transmission quality was evaluated. In addition, assume that one terminal station executed transfer function estimation with respect to each of three base stations. The number of 5 times of weight update by the algorithm of the present invention was 100.

Referring to Fig. 6, the distances between base stations are compared about the characteristics at 10 dB of the ordinate. The distance between base 10 stations is 600 m for the conventional autonomous distributed control. However, it can be shortened to 400 m, i.e., about 2/3 or less, in the present invention.

That is, when the adaptive antennae of a plurality of base stations are controlled altogether, 15 the transmission quality of a communication channel whose transmission quality considerably degrades can be improved, and the interference in the downlink can be reduced in the entire system

Uplink control will be described next with 20 reference to Fig. 2. For the descriptive convenience, this example assumes that the base station 102(1) and terminal station 101(1) communicate, and control is executed to suppress the interference for reception at the base station 102(1) by signals transmitted from the 25 remaining two terminal stations 101(2) and 101(3) which use the same communication channel and also to reduce interference for all the plurality of base stations

102(1), 102(2), and 102(3).

Although the terminal stations 101(2) and 101(3) are not illustrated in Fig. 2, they perform the same operation of that of the terminal station 101(1).  
5 Referring to Fig. 2, first, the terminal station 101(1) transmits the predetermined known signal St to each of the base stations 102(1), 102(2), and 102(3). In this case, the signals St are transmitted using different communication channels. That is, communication channels  
10 for which at least one of the frequency, timing, and spreading code is different are used.

In step S31, each of the base stations 102(1), 102(2), and 102(3) checks the correlation between the signal (St) held by itself and the reception signal  
15 received from the terminal station 101(1), thereby estimating a transfer function. A transfer function is obtained for each antenna element of each base station 102. In addition, the base stations 102(1), 102(2), and 102(3) individually estimate transfer functions for each  
20 of the plurality of terminal stations 101(1), 101(2), and 101(3).

To estimate a transfer function, a method indicated by, e.g., reference (D. Gerlach and A. Paulraj,  
Acoustics, Speech and Signal Processing, ICASSP, vol. 4,  
25 pp. IV/97 - IV100, 1994) is used. All transfer functions estimated by the base stations 102(1), 102(2), and 102(3) are transferred to the intensive control

station 103.

On the basis of the transfer function received for each antenna element, each base station, or each terminal station, the intensive control station 103 determines a weight vector for the adaptive antenna in each of the base stations 102(1), 102(2), and 102(3) and the transmission power of each of the terminal stations 101(1), 101(2), and 101(3) such that the interference power at all the base stations 102(1), 102(2), and 102(3) is minimized.

Assume that the nth base station 102 communicates with the mth terminal station 101. An interference power  $U(n)$  that the nth base station 102 receives from the plurality of terminal stations 101 other than the mth terminal station 101 is given by

$$U(n) = \sum_{k=1(k \neq m)}^K \left| \sum_{j=1}^P w_{u(k,j)} V_{u(m,k,j)} \right|^2 \quad \dots (23)$$

$w_{u(k,j)}$ : weight for antenna element in uplink

$V_{u(m,k,j)}$ : transfer function of antenna element in uplink

P: number of antenna elements

N: number of base stations

When the plurality of base stations 102 are simultaneously communicating, the interference is preferably reduced for the entire system. For example, when the interference power at the base station 102(1) is small but that at the base station 102(2) is large,

the transmission quality in the entire communication system degrades, and this need be improved. Hence, in a communication channel with a lowest transmission quality, the transmission power of the terminal station 101 is 5 preferably increased. In a communication channel with a high transmission quality, no problem is posed even when the transmission power of the terminal station 101 is suppressed.

To control the interference on the plurality 10 of base stations 102 altogether, the intensive control station 103 executes control by obtaining an evaluation index  $E_{up}$  of the entire uplink from

$$E_{up} = \sum_{k=1}^N U(k) \quad \dots (24)$$

N: number of base stations

15 That is, the intensive control station 103 selects a combination of weight vectors for the base stations 102 and a combination of transmission powers of the terminal stations 101, with which the evaluation index  $E_{up}$  is minimized, thereby suppressing degradation 20 in transmission quality due to the interference to the minimum.

As shown in Fig. 2, the weight vectors determined by the intensive control station 103 are transferred to the base stations 102(1), 102(2), and 25 102(3). In addition, the values of transmission powers determined by the intensive control station 103 are

transferred to the terminal stations 101 through the base stations 102.

Each of the base stations 102(1), 102(2), and 103(3) supplies to the weighting circuit 912 of the adaptive antenna the weight vector assigned to itself by the intensive control station 103. With this processing, the directional patterns of the antennas of the base stations 102(1), 102(2), and 102(3) are determined.  
5  
Each terminal station 101 adjusts its transmission power in accordance with the transmission power assigned by the control of the intensive control station 103.  
10

The characteristic of the uplink in executing the control shown in Fig. 2 was simulated using a computer. Fig. 7 shows the result compared with a conventional method. This simulation was done assuming the following conditions.  
15

All base stations and terminal stations were completely synchronized, and the base stations and terminal stations transmitted signals with the same frequency, timing, and spreading code.  
20

Radius of cell formed by base station: 250 m  
Number of antenna elements of adaptive antenna of each base station: 4 elements  
Layout of antenna elements: circular array  
25  
Directivity of antenna element:  
omni-directional in horizontal plane  
Antenna element spacing:  $0.5\lambda$

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Delay profile: exponential model  
Delay spread: 0.1 symbol length  
Number of base stations: 36  
Number of terminal stations: 36  
Angular spread of incoming wave: 120°  
For the conventional method, assume that the adaptive antennae were individually controlled for the respective base stations, and each terminal station controlled its transmission power such that the reception level at the base station had a predetermined value.

The layout of the terminal stations was changed 100 times at random, and the 50% value of the cumulative probability of the transmission quality of a terminal station with a lowest transmission quality was evaluated. In addition, assume that one terminal station executed transfer function estimation with respect to each of three base stations. The number of times of weight update by the algorithm of the present invention was 100.

Referring to Fig. 7, the distances between base stations are compared about the characteristics at 10 dB of the ordinate. The distance between base stations is 600 m for the conventional autonomous distributed control. However, it can be shortened to 400 m, i.e., about 2/3 or less, in the present invention.

That is, when the adaptive antennae of a

plurality of base stations are controlled altogether,  
the transmission quality of a communication channel  
whose transmission quality considerably degrades can be  
improved, as in the downlink, and the interference in  
5 the uplink can be reduced in the entire system  
(Second Embodiment)

An adaptive antenna control method according  
to another embodiment of the present invention will be  
described with reference to Figs. 4, 5, and 8. This  
10 second embodiment corresponds to claims 5 and 10.

Fig. 4 shows control of an intensive control  
station related to a downlink according to the second  
embodiment

Fig. 5 shows control of the intensive control  
15 station related to an uplink according to the second  
embodiment.

Fig. 8 shows the characteristic of the second  
embodiment. The second embodiment is a modification to  
the first embodiment. The second embodiment is the same  
20 as the first embodiment except that the contents of  
control by an intensive control station 103 are changed  
as shown in Figs. 4 and 5. For the same parts as in the  
first embodiment, a description thereof will be omitted.

Control of the downlink will be described  
25 first with reference to Fig. 4. As in Fig. 1, transfer  
functions estimated by a terminal station 101(1) are  
input to the intensive control station 103 through base

stations 102. On the basis of the transfer functions,  
 the intensive control station 103 determines the  
 downlink directional pattern of the antenna of each base  
 station 102. When transfer functions necessary for  
 5 control are input, processing by the intensive control  
 station 103 advances from step S21 to S22. In step S22,  
 a conventional adaptive antenna control algorithm (e.g.,  
 R.A. Monzingo and T.W. Miller, "Introduction to Adaptive  
 Arrays", John Wiley & Sons, Inc. 1980) is applied to  
 10 each base station 102, thereby obtaining the downlink  
 weight vector of the adaptive antenna of each base  
 station 102 for autonomous distributed control.

$$Wd(n) = G(m) \left( \sum_{k=1}^K G(k)^2 Vd(k,n) Vd(k,n)^H \right)^{-1} Vd(m,n) \quad \dots (25)$$

$$15 \quad G(m) = \frac{\text{Re}(Wd(n)^H Vd(m,n))}{\sum_{k=1}^N (Wd(k)^H Vd(m,k) Vd(m,k)^H Wd(k)) + |\sigma(m)|^2} \quad \dots (26)$$

where

$\sigma(m)$ : noise power of mth terminal station

Re : real number portion

20 suffix H: complex conjugate transposition

$$Wd(n) = \begin{pmatrix} wd(n,1) \\ wd(n,2) \\ \vdots \\ wd(n,P) \end{pmatrix}$$

25  $wd(n,1)$  to  $wd(n,P)$ : weights for antenna  
elements

P: number of antenna elements of nth base station

Vd(m,n): transfer function vector of downlink communication between mth terminal station and nth base station

5

$$Vd(m,n) = \begin{pmatrix} vd(m,n,1) \\ vd(m,n,2) \\ \vdots \\ vd(m,n,P) \end{pmatrix}$$

10 vd(m,n,1) to vd(m,n,P): transfer functions of antenna elements

N: number of base stations

K: number of terminal stations

Assume communication between nth base station and mth terminal station

15

In step S23, the weight vector obtained in step S22 is substituted as an initial value into a weight vector Wd(n) of equation (25). In step S24, a gain G(m) of equation (26) is calculated. In step S25, the weight vector Wd(n) of equation (25) is re-calculated using the gain G(m).

20

Until the arithmetic result converges, calculations in steps S24 and S25 are alternately repeated. In step S26, it is identified whether the arithmetic result has converged. For this determination, for example, a signal-to-interference-power ratio in a communication channel with a lowest transmission quality

25

is compared with a predetermined threshold value. That is, it can be regarded that the arithmetic result has converged when the transmission quality of a most degraded communication channel exceeds the lower limit

5 value.

When the arithmetic result has converged, the flow advances from step S26 to S27 to transmit the weight vector  $W_d(n)$  as the final arithmetic result to each base station 102.

10 In the second embodiment as well, the directional patterns of the antennas of the plurality of base stations 102 can be controlled altogether.

An arithmetic result convergence characteristic in executing the control shown in Fig. 4 was simulated using a computer. Fig. 8 shows the result. This simulation was done assuming the following conditions.

Number of base stations: 2  
Number of terminal stations: 2

20 Distance between base stations: 500 m

Also assume that the transfer functions could be estimated without any error. Referring to Fig. 8, the control shown in Fig. 4 does not diverge but converge with update about 100 times. An interference characteristic in employing the control shown in Fig. 4 was simulated, and consequently, a result that completely matched Fig. 6 was obtained.

That is, even in executing the control shown in Fig. 4, the downlink directional patterns of the base stations can be determined altogether such that the total interference power in the plurality of 5 communication channels is minimized, as in the first embodiment.

Control of the uplink will be described first with reference to Fig. 5. As in Fig. 2, transfer functions estimated by each base station 102 are input 10 to the intensive control station 103. On the basis of the transfer functions, the intensive control station 103 determines the uplink directional pattern of the antenna of each base station 102 and the transmission power of each terminal station 101.

15 When transfer functions necessary for control are input, processing by the intensive control station 103 advances from step S41 to S42. In step S42, a conventional adaptive antenna control algorithm (e.g., R.A. Monzingo and T.W. Miller, "Introduction to Adaptive 20 Arrays", John Wiley & Sons, Inc. 1980) is applied to each base station 102, thereby obtaining the uplink weight vector of the adaptive antenna of each base station 102 for autonomous distributed control.

$$25 \quad Wu(n) = Gt(m) \left( \sum_{k=1}^K Gt(k)^2 Vu(k,n) Vu(k,n)^H \right)^{-1} Vu(m,n) \quad \dots (3)$$

$$G_t(m) = \frac{\operatorname{Re}(W_u(n)^H V_u(m,n))}{\sum_{k=1}^N (W_u(k)^H V_u(m,k) V_u(m,k)^H W_u(k)) + (W_u(n)^H W_u(n) |\sigma(m)|^2)} \quad \dots (4)$$

where

5  $\sigma(n)$ : input noise power of nth base station

$W_u(n)$ : weight vector of nth adaptive antenna system

10  $\operatorname{Re}$  : real number portion

suffix H: complex conjugate transposition

$$W_u(n) = \begin{pmatrix} w_u(n,1) \\ w_u(n,2) \\ \vdots \\ w_u(n,P) \end{pmatrix}$$

15  $w_u(n,1)$  to  $w_u(n,P)$ : weights for antenna elements

20 P: number of antenna elements of nth base station

$V_u(m,n)$ : transfer function vector of uplink communication between mth terminal station and nth base station

$$V_u(m,n) = \begin{pmatrix} v_u(m,n,1) \\ v_u(m,n,2) \\ \vdots \\ v_u(m,n,P) \end{pmatrix}$$

25  $v_u(m,n,1)$  to  $v_u(m,n,P)$ : transfer functions of antenna elements

N: number of base stations

K: number of terminal stations

Assume communication between nth base station  
and mth terminal station

5        In step S43, the weight vector obtained in  
step S42 is substituted as an initial value into a  
weight vector  $W_u(n)$  of equation (27). In step S44, a  
transmission power  $G_t(m)$  of equation (28) is calculated.  
In step S45, the weight vector  $W_u(n)$  of equation (27) is  
10      re-calculated using the transmission power  $G_t(m)$ .

Until the arithmetic result converges,  
calculations in steps S44 and S45 are alternately  
repeated. In step S46, it is identified whether the  
arithmetic result has converged. For this determination,  
15      for example, a signal-to-interference-power ratio in a  
communication channel with a lowest transmission quality  
is compared with a predetermined threshold value. That  
is, it can be regarded that the arithmetic result has  
converged when the transmission quality of a most  
20      degraded communication channel exceeds the lower limit  
value.

When the arithmetic result has converged, the  
flow advances from step S46 to S47 to transmit the  
weight vector  $W_u(n)$  as the final arithmetic result to  
25      each base station 102. In addition, the transmission  
power  $G_t(m)$  as the final arithmetic result is  
transmitted to each terminal station 101. In the second

embodiment as well, the uplink directional patterns of the antennas of the plurality of base stations 102 and the transmission powers of the plurality of terminal stations 101 can be controlled altogether.

5 An arithmetic result convergence characteristic in executing the control shown in Fig. 5 was simulated using a computer. The same result as in Fig. 8 was obtained. That is, even in executing the control shown in Fig. 5, the uplink directional patterns 10 of the base stations and the transmission powers of the terminal stations can be determined altogether such that the total interference power in the plurality of communication channels is minimized, as in the first embodiment.

15 (Third Embodiment)

Fig. 10 shows the third embodiment. This third embodiment corresponds to claims 11 to 24.

Claims 11 and 12 are to control the directivity of the antenna of each base station on the basis of transmission/reception signals exchanged 20 between two or more base stations and two or more terminal stations.

That is, as shown in Fig. 10, at least two terminal stations 101A and 101B are present in radio zones A and B of a plurality of base stations 102A and 25 102B. When the terminal stations 101A and 101B are transmitting/receiving radio wave signals to/from the

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base stations 102A and 102B, respectively, using the same communication channel with the same frequency and same timing, an intensive control station 103 receives through the terminal stations 101A and 101B at least one 5 of the transmission signal from each of the terminal stations 101A and 101B and the reception signal at each of the terminal stations 101A and 101B, which is received and transmitted by each of the terminal stations 101A and 101B, generates weight vectors for 10 minimizing the interference power on the basis of the received signals, and transmits the weight vectors to the base stations 102A and 102B as control signals to change the directivity characteristics of the antennas of the base stations 102A and 102B such that the 15 interference power between the terminal stations 101A and 101B is reduced.

In this case, the base stations 102A and 102B are connected, and the above-described function of the intensive control station 103 is imparted to one of the 20 base stations 102A and 102B, e.g., the base station 102A to cause the base station 102A to receive through the base station 102B a signal from the terminal station 101B that is communicating with the base station 102B and also receive a signal from the terminal station 101A 25 connected to itself. On the basis of the received signals, the base station 102A generates control signals for reducing the interference power between the terminal

stations 101A and 101B to change the directivity of antenna of itself and also to change the directivity characteristic of the antenna of the base station 102B by transmitting the generated control signal to the base station 102B. With this arrangement, the intensive control station 103 can be omitted.

As described in claim 13, the intensive control station 103 obtains the field strength and spatial correlation characteristic of each base station on the basis of a signal transferred from each base station and determines, on the basis of the obtained field strength and spatial correlation characteristic, a base station whose directivity characteristic of the antenna is to be changed.

Generally, when the terminal stations 101A and 101B which execute radio communication with the base stations 102A and 102B, respectively, are present on lines that connect the base stations 102A and 102B, as shown in Fig. 10, the spatial correlation characteristic of each of the base stations 102A and 102B is supposed to be high. In claim 13, when a plurality of base stations are present, the intensive control station 103 receives a signal transferred from each base station and obtains the field strength and spatial correlation characteristic of each base station on the basis of the received signal. When at least one of the base stations has a high spatial correlation characteristic, the base

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stations 102A and 102B which have high reception field levels and the positional relationship as shown in Fig. 10 are selected and determined as base stations whose directivity characteristics of the antennas are to 5 be changed.

In each of the base stations 102A and 102B, an antenna comprises a plurality of antenna elements 901, and weighting circuits 902 and 912 for respectively weighting the transmission/reception signals to/from the 10 plurality of antenna elements, as shown in Fig. 9 described above. The directivity characteristic of the antenna is changed by causing the weighting circuits to weight the transmission/reception signals transmitted/received to/from the plurality of antenna elements. That is, as in claim 14, a base station has 15 an adaptive antenna comprising an antenna formed from a plurality of antenna elements, and weighting circuits for respectively weighting the transmission/reception signals to/from the plurality of antenna elements, and the directivity characteristic of the antenna is changed by causing the weighting circuits to weight the 20 transmission/reception signals transmitted/received to/from the plurality of antenna elements.

In the terminal stations 101A and 101B, upon 25 receiving signals transmitted from the plurality of neighboring base stations 102A and 102B, transfer functions are estimated as described above by checking

the correlation between the reception signals and known signals held by themselves in advance. The estimated transfer functions are transmitted to the base stations 102A and 102B. Upon receiving the transfer functions,  
5 the base stations 102A and 102B transmit the transfer functions to the intensive control station 103. As in claim 16, the intensive control station 103 calculates weight vectors using, as parameters, the transfer functions and the predicted values of the reception  
10 levels of the terminal stations. On the basis of the calculated weight vectors, the intensive control station 103 calculates the sum of square errors between the reception signals (i.e., transmission signals of the base stations 102A and 102B) at the terminal stations  
15 101A and 101B using the same communication channel and desired signals d corresponding to the reception signals and repeatedly calculates the weight vectors by repeatedly changing the parameters until the sum of square errors becomes smaller than a predetermined  
20 threshold value. On the basis of weight vectors obtained when the sum of square errors becomes smaller than the threshold value, the weights of the antennas of the base stations 102A and 102B are determined. In this case, as in claim 15, the above-described function of  
25 the intensive control station 103 may be imparted to the base stations 102A and 102B such that the base stations 102A and 102B change the directivity characteristics of

their antennas on the basis of the transfer functions received from the terminal stations 101A and 101B.

In this case, as in claim 17, on the basis of the calculated weight vectors, the sum of square errors 5 between the reception signals at the terminal stations 101A and 101B using the same communication channel and the desired signals  $d$  corresponding to the reception signals may be calculated, and the weight vectors may be repeatedly calculated by repeatedly changing the 10 parameters until the maximum value of square errors at the terminal stations 101A and 101B becomes smaller than a predetermined threshold value. On the basis of weight vectors obtained when the maximum of square errors becomes smaller than the threshold value, the weights of 15 the antennas of the base stations 102A and 102B may be determined.

The above method can be actually realized by executing the processing in steps S23 to S26 shown in the flow chart of Fig. 4. That is, as in claim 18, a 20 weight vector obtained in step S22 of Fig. 4 is substituted as an initial value into a weight vector  $W_d(n)$  of equation (25). In step S24, a gain (the reciprocal of the predicted value of the reception level)  $G(m)$  of equation (26) is calculated. In step S25, 25 the weight vector  $W_d(n)$  of equation (25) is re-calculated using the gain  $G(m)$ . Until the arithmetic result converges, calculations in steps S24 and S25 are

alternately repeated. In this case, as in claim 19, a signal-to-interference-power ratio in a communication channel with a lowest transmission quality may be defined as the threshold value, and the weights of the 5 antennas of the base stations 102A and 102B may be determined on the basis of the weight vectors obtained when the maximum value of the square errors becomes smaller than the threshold value.

In the base stations 102A and 102B, upon 10 receiving signals transmitted from the terminal stations 101A and 101B, transfer functions are estimated as described above by checking the correlation between the reception signals and known signals held by themselves in advance. The estimated transfer functions are 15 transmitted to the intensive control station 103. As in claim 21, the intensive control station 103 calculates weight vectors using, as parameters, the transfer functions and transmission power values to be set for the terminal stations 101A and 101B. On the basis of 20 the calculated weight vectors, the intensive control station 103 calculates the sum of square errors between the transmission signals (i.e., the reception signals of the base stations 102A and 102B) at the terminal stations 101A and 101B using the same communication 25 channel and the desired signals d corresponding to the transmission signals and repeatedly calculates the weight vectors by repeatedly changing the parameters

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until the sum of square errors becomes smaller than a predetermined threshold value. On the basis of weight vectors obtained when the sum of square errors becomes smaller than the threshold value, the weights of the 5 antennas of the base stations 102A and 102B are determined. In this case, as in claim 20, the above-described function of the intensive control station 103 may be imparted to the base stations 102A and 102B such that the base stations 102A and 102B 10 change the directivity characteristics of their antennas on the basis of the transfer functions estimated by themselves.

In this case, as in claim 22, on the basis of the calculated weight vectors, the sum of square errors 15 between the transmission signals at the terminal stations 101A and 101B using the same communication channel and the desired signals  $d$  corresponding to the transmission signals may be calculated, and the weight vectors may be repeatedly calculated by repeatedly 20 changing the parameters until the maximum value of square errors at the terminal stations 101A and 101B becomes smaller than a predetermined threshold value. On the basis of weight vectors obtained when the maximum 25 of square errors becomes smaller than the threshold value, the weights of the antennas of the base stations 102A and 102B may be determined.

The above method can be actually realized by

executing the processing in steps S43 to S46 shown in the flow chart of Fig. 5. That is, as in claim 23, a weight vector obtained in step S43 of Fig. 5 is substituted as an initial value into a weight vector  
5  $W_u(n)$  of equation (27). In step S44, a transmission power  $G_t(m)$  of equation (28) is calculated. In step S45, the weight vector  $W_u(n)$  of equation (27) is re-calculated using the transmission power  $G_t(m)$ .

Until the arithmetic result converges,  
10 calculations in steps S44 and S45 are alternately repeated. In this case, as in claim 24, a signal-to-interference-power ratio in a communication channel with a lowest transmission quality may be defined as the threshold value, and the weights of the  
15 antennas of the base stations 102A and 102B may be determined on the basis of the weight vectors obtained when the maximum value of the square errors becomes smaller than the threshold value.

As has been described above, according to the  
20 present invention, since a plurality of adaptive antennae each having an interference reduction capability are controlled altogether such that the total interference power at the terminal stations is minimized in the downlink and the total interference power at the  
25 base stations is minimized in the uplink communication, the interference can be reduced in the entire system both for the uplink and downlink communications.

Hence, the distance between base stations which use the same frequency can be made shorter than in a conventional adaptive antenna. That is, the frequency use efficiency can be improved, and a high-speed radio communication system that requires a wide frequency band can be implemented within a limited band.